CHAPTER 3

BENEFIT ESTIMATION

I. General

Benefits are the outputs of goods or services that are produced by the investments, operations and regulations of a government agency. Most frequently they are provided to the public but may on occasion be furnished to other governmental agencies. When valued in dollars, benefits are analogous to (but not identical with) private sector revenues. However, unlike the private sector where products are sold and their value established in the market place, most governmental outputs frequently are provided free or at arbitrary prices. As a consequence, measurement of benefits can be a formidable task.

A related outcome of government operations or regulations are cost savings. While savings benefits do not represent products or services delivered to the consumer, they are reductions in the cost of delivering these items. The savings provide resources which may be used in other activities to produce new goods and services. Thus, savings should be treated as benefits because they represent value to the government and/or private parties which arises as the result of undertaking a project or regulation and incurring its life cycle cost.

The benefit estimation procedure is a three step process. The first step is to identify what effects will occur and who will be affected as a consequence of undertaking an activity. This can be difficult in itself if the proposed activity is large and/or complex. The second step is to measure these effects in physical units. Finally, the physical units must be valued in dollars. Suggested procedures for accomplishing these tasks are detailed in Section III. A theoretical basis for valuation is considered in Section II.

II. Benefit Valuation

A. A Concept of Value

Before beginning a discussion of how to value specific benefits, it is important to know what is meant by value and how it can be measured. In this discussion a principal distinction lies between the value of a product to consumers and the amount of money they must spend to acquire the product. When a consumer voluntarily exchanges money for a specific commodity, the consumer indicates that the value placed on the specific commodity equals or exceeds the value placed on what that amount of money could buy in its next most valued use. If it did not, the consumer would not voluntarily make such an exchange. Thus, the amount of money expended on a commodity is a minimum measure of the value of a commodity to a consumer. The total value of a commodity is measured by the maximum amount of money a consumer would be willing to give up and still be willing to voluntarily engage in the exchange. The concept of value measurement may be clarified with reference to the economist's concept of the demand curve.

Figure 3-1 presents a typical demand curve for a particular commodity. The curve indicates the quantity of the commodity that consumers as a whole will purchase at any particular price. It slopes downward to the right because consumers can be expected to purchase larger quantities at lower prices than at higher ones. A useful property of the demand curve is that it traces out the prices which consumers are just willing to pay for an additional unit of a commodity for all different quantities actually purchased. This price represents the marginal value placed by consumers on an additional unit of the commodity. In Figure 3-1, the demand curve shows that consumers can be expected to buy quantity Q_1 at price P_1. To induce consumers to increase purchases by one unit to Q_2, price must fall to P_2. Thus, the maximum price that will be paid for one more unit, provided that Q_1 units are currently being purchased, is P_2. Or in other words, P_2 is the marginal valuation which consumers place on this unit of the commodity. To determine the marginal value of each successive unit, it is necessary to repeat the process. The total value to the consumers of a number of units is obtained by summing the marginal valuations.[1]

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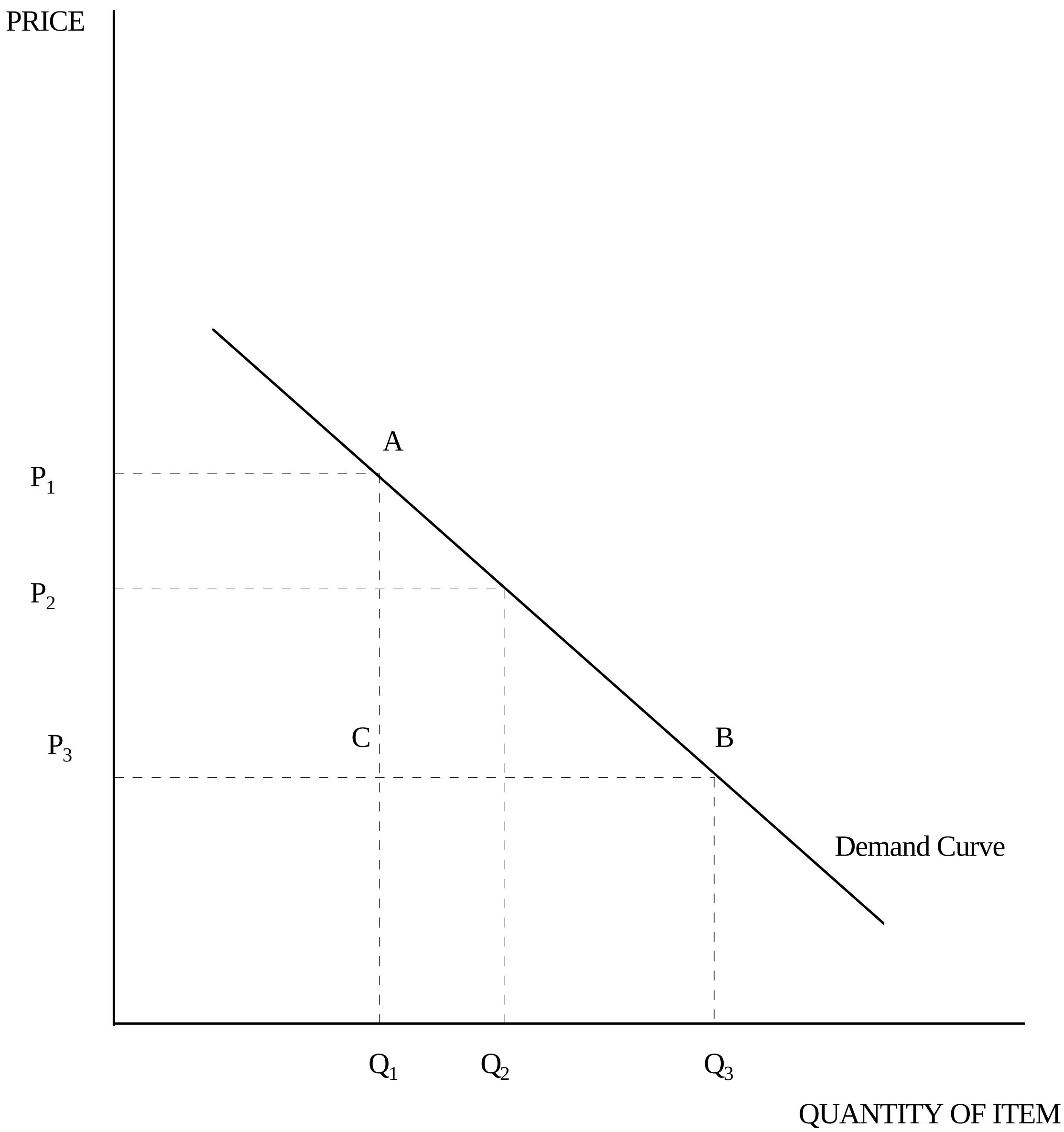
[1] The demand curve described here is known as a “compensated” demand curve along which real income is held constant. It is different from the commonly observed empirical demand curve along which real income changes. However, in most situations including those faced by FAA, empirically observed demand curves will closely approximate “compensated” ones and can be used directly in benefit-cost analysis without adjustment. For an introductory discussion of this issue, see Mark Blaug, *Economic Theory in Retrospect*, Richard D. Irwin, Inc., Homewood, Illinois, 1968, pp. 359-373.

FIGURE 3-1

TYPICAL DEMAND CURVE



In Figure 3-1, the sum of the marginal valuations of units $Q_3 - Q_1$ is represented by the area Q_1ABQ_3. This area represents the maximum amount consumers would be willing to pay for units $Q_3 - Q_1$. It consists of rectangle Q_1CBQ_3 plus triangle ACB. Rectangle Q_1CBQ_3, equal to P_3 x $(Q_3 - Q_1)$, equals the total amount consumers would be required to pay for $Q_3 - Q_1$ at P_3. Triangle ACB represents additional value of the units $Q_3 - Q_1$ overand above this payment which consumers would be willing to pay rather than go without these units of the commodity.

B. Benefits of FAA Actions

Most FAA investment projects, AIP grants, and regulatory actions are intended to reduce the costs of air transportation. Cost reductions accrue to the flying public through reduced accident costs, reduced delay costs, and in other ways. To the extent that FAA activities result in relatively small cost reductions, the benefits of such activities may be valued based on current system use without taking into account any increase in system usage resulting from cost reductions. With reference to Figure 3-1, assume that an FAA action causes the per unit cost of using some segment of the system to fall from P_1 to P_2. The value of this to the current users of the service may be approximated by $(P_1 - P_2)$ x Q_1. Although this procedure understates the true increase in value by ignoring the value of unit $Q_2 - Q_1$, the amount of error is small enough that it can be ignored for practical purposes.

For activities that result in larger cost reductions to the public, the value of additional units which will be demanded must be considered or the total increase in value will be substantially understated. In terms of Figure 3-1, if costs are reduced from P_1 to P_3, consumers of Q_1 units will be benefited by $(P_1 - P_3)$ x Q_1. But the reduction of $P_1 - P_3$ will also induce the additional units of $Q_3 - Q_1$ to be demanded, both by current and new consumers. The value of these units is equal to the sum of the their marginal valuations as indicated by area Q_1ABQ_3. The magnitude of the cost reduction makes this amount large enough that it can no longer be ignored.

Frequently, the value of additional units such as $Q_3 - Q_1$ are measured net of the costs which consumers must bear to consume them. The resulting net benefit is then compared to other public and private costs in the benefit-cost analysis. In Figure 3-1, the net benefit would be represented by triangle ACB under this procedure. This is equal to the sum of the marginal valuations, Q_1ABQ_3, less the amount consumers are required to pay, as shown by rectangle Q_1CBQ_3. (Note, this procedure is strictly a convention. The same result would occur if total benefits of units $Q_3 - Q_1$, Q_1ABQ_3, were counted under benefits and consumer borne costs, Q_1CBQ_3, considered under costs in Chapter 4.)The total net benefit of a project is equal to the sum of the benefits to current consumers plus that associated with the additional units demanded because of lower costs. In Figure 3-1, this amount is indicated by area P_1ABP_3.

For commodities traded in markets, value may be determined with reference to observed market behavior of consumers. For many items produced by government or brought about by government investments, grants, or regulation, value cannot be determined by reference to market behavior because the items are not traded in markets. Rather, they are provided free or at arbitrary prices. Nonetheless, they may be valued by determining the maximum amount consumers would be willing to pay for them. The following section outlines methodology for estimating the value of benefits provided by FAA investments, AIP grants, and regulatory activities.

III. Benefit Categories

There are three primary areas in which FAA investments, AIP grants, and regulations generate benefits. These are safety improvement, capacity increases including congestion related delay reductions and avoided flight disruptions, and cost savings. Other benefits outside of these three areas also frequently occur and should be included in any particular analysis using appropriate methodology for the particular circumstance. Each of these benefit areas is now considered.

A. Safety

Safety may be defined in terms of the risk of death, personal injury, and property damage which results from air transportation accidents. A major responsibility of FAA is to reduce the incidence of such outcomes. FAA carries out this function through its capital investment, operations, and regulatory functions. The evaluation of the benefits of such activities requires determination of the extent to which deaths, injuries, and property damage resulting from preventable accidents will be reduced, and that these reductions be valued in dollars. This subsection presents methodology for determining deaths, injuries, and damages prevented by risk reduction. Once known, these can be valued in dollars by applying standardized DOT and FAA economic values.[2]

[2] See “Treatment of Value of Life and Injuries in Preparing Economic Evaluations,” Office of the Secretary of Transportation Memorandum, January 6, 1993 and subsequent annual updates; and *Economic Values for Evaluation of Federal Aviation Administration Investment and* Regulatory *Programs*, Federal Aviation Administration, Report FAA-APO-89-10, October 1989.

1. Unit of Exposure

Meaningful accident measurement requires that accidents be stated as a rate per some unit of exposure. Such a unit should have the characteristic that each time it occurs an accident of a particular type either can or cannot result. The appropriate unit of exposure will differ depending on the type of accident under consideration. Every aircraft movement from one point to another consists of several components: departure taxi, take off, climb out, enroute cruise, descent, approach, landing, and arrival taxi. All components other that the enroute cruise will have approximately the same duration each time they occur and will be approximately independent of the duration of the enroute component. Moreover, each component other that the enroute one constitutes a self contained phase of flight which is approximately the same from one flight to another and which must be undertaken each and every time an aircraft is flown from one place to another. Accordingly, because the risk of an accident can be considered to be approximately independent of the duration of a flight for all but the enroute component, the appropriate measure of exposure for other than enroute accidents should not vary with the duration of a flight.

For the enroute component of a flight, the opportunity for an accident to occur is present throughout its duration. The longer the enroute component lasts, the greater the exposure to the risk. Consequently, appropriate exposure measures for the enroute component should vary with the duration of the flight. In the case of enroute turbulence accidents, the exposure measure should also vary with the number of passengers transported. This is because the chance that at least one passenger's seat belt will be unfastened at the same time an aircraft encounters turbulence, thus creating an opportunity for a turbulence accident, varies with the number of passengers, as well as with the duration of the flight.

For the most part, all flight segments except the enroute one occur primarily in the terminal area. Acceptable exposure measures are operations and instrument operations.[3] An operation occurs each time an aircraft either takes off or lands. An instrument operation occurs each time an aircraft on an instrument flight plan takes off or lands. A third measure, instrument approaches (as distinct from instrument operations), occurs each time an aircraft on an instrument flight plan makes an instrument approach under instrument weather conditions. Although conceptually acceptable and used in many previous analyses, instrument approach counts are subject to errors. Moreover, in many applications it is necessary to estimate the number of instrument approaches that would be expected to occur if an instrument approach should be installed where one does not now exist. Accordingly, it is not recommended that this measure be used. Rather, instrument approaches should be estimated directly from operations and weather data. Acceptable techniques for and applications of such estimation may be found in “Preliminary Analysis

[3] Data may be found on Office of Aviation Policy and Plans Home Page, http://api.hq.faa.gov/apo_home.htm.

of the Correlation Between Annual Instrument Approaches, Operations and Weather," Federal Aviation Administration, Report No. DOT-FAA-78WA-4175, December 1980, *Establishment and Discontinuance Criteria for Precision Landing Systems*, Federal Aviation Administration, Report No. FAA-APO-83-10, September 1983, Appendix C, and *Establishment Criteria for LORAN-C Approach Procedures*, Federal Aviation Administration, Report No. FAA-APO-90-5, pp. 7-8.

For accidents which occur enroute such as those resulting from engine failure or flight system failure, exposure measures related to flight duration are appropriate. Acceptable measures are hours flown or miles flown. Measures which also reflect the number of passengers carried such as passenger miles, the product of miles flown and passengers carried, should not be used because the risk of these types of enroute accidents is not dependent on the number of passengers being carried. (For enroute turbulence accidents, measures such as passenger miles are acceptable.)[4]

2. Models

One method of determining prevented deaths, injuries and property damage is to construct a model which relates these items to a unit of exposure. Such a model typically computes the number of accidents that can be expected to occur per unit of exposure both with and without a particular system in place. The difference is the number of prevented accidents. The actual estimating procedure can be as simple as calculating accidents as a fraction of the exposure unit. Or it can be complex, allowing the probability of an accident to vary with a host of other factors such as weather, aircraft types, length of runway, etc.[5]

Prevented deaths, injuries, and property damage can then be ascribed to the prevented accidents using historical averages for these types of accidents for fatalities, minor and serious injuries, and damage per accident. Because there is wide variation in fatalities, injuries and property damage by type and size of aircraft, as well as by passenger loads, it is important that the averages used reflect the aircraft types and passenger loads likely to have been involved in the prevented accidents. This can be accomplished by using different averages for different airports or air routes.

3. Judgmental Accident Evaluation

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[4] *Air Carrier Traffic Statistics*, Bureau of Transportation Statistics, U.S. Department of Transportation, published monthly.

[5] A simple model that relates terminal area mid-air collisions, both with and without an airport traffic control tower, to traffic levels is developed in *Establishment and Discontinuance Criteria For Airport Traffic Control Towers*, FAA Report FAA-APO-90-7, August 1990.

A second method for determining prevented accidents is to examine a large number of accidents of a particular type and make a judgmental determination of which ones could have been prevented by the investment or regulation in question and which ones could not have been. To add validity to the work, it is often desirable to have the analysis of accidents undertaken by a group of knowledgeable individuals so as to avoid the biases of any one particular person. In those cases where a decision between classifying an accident as preventable or not preventable is a toss-up, it should be classified as preventable by convention. This is done to let the benefits of any doubt favor making the investment or implementing the regulation.

The judgmental method has the advantage of simplicity and ease. Moreover, it does not have the large data requirements typically associated with model estimation. It has the disadvantage of almost always overstating the benefits of any proposed activity. This occurs because some accidents judged preventable would still have occurred. A given safety program will be successful in preventing only a certain percentage of all potentially preventable accidents. This percentage is generally unknown. Note, however, that a proposed activity which fails to muster benefits in excess of costs when the judgmental method is used is probably not worth undertaking.

4. Estimating Accident Risks Absent Historical Data

Often it is necessary to determine accident risks when there are not historical data. This situation can arise under a number of circumstances. These include cases where common sense tells us that the probability of an accident is not zero yet no accident has ever occurred. (This could occur either because the probability of a accident is very small and one has just not happened yet despite numerous opportunities--such as an aircraft crashing into a nuclear power plant--or because a new technology is involved and there has been limited opportunities for accidents to happen--such as with high intensity radiated fields interference with aircraft systems.) Another would be when it is necessary to make estimates outside of the range of previously observed data, as is the case with issues involving aging aircraft.

In all such cases, it should be recognized that an accident risk estimate is a forecast which should be based on a logical extrapolation of all currently available information and data. In fact, the choice of an estimating approach will often be driven by the amount and quality of data available. There are several ways to proceed, including:

- Analytical deduction: Although there may be no direct observations of accidents themselves, frequently information and data will exist concerning the processes which produce the accidents of interest. In such cases, it may be possible to construct models of the accident process, assign values to model parameters using data which is available, and analytically calculate accident risk estimates. Examples of this approach include fault tree analysis (FTA) and failure modes and effects analysis (FMEA).[6]

- Analogies: Despite the lack of historical data specific to the problem at hand, there may exist similar but not identical situations from which accident risk estimates can by made by analogy, with appropriate adjustment--either judgmental or analytical--to reflect the differences between the analogous situation and the one of interest. Such an approach essentially involves an extrapolation beyond the range of available data. It can be expected to be progressively less representative the greater the range of extrapolation.

- Statistical estimation: Often limited but incomplete information or data may exist. In such cases it may be possible to develop estimates of accident risk using certain statistical techniques including selected Bayesian methods. Such procedures combine existing or prior information--developed either empirically or from expert opinion--with situation-specific information (often of a limited nature) in a systematic fashion to yield the desired estimates.[7]

5. National Aviation Safety Data Analysis Center

Numerous data bases suitable for safety benefit development are maintained by FAA in the National Aviation Safety Data Analysis Center (NASDAC). These include both data on accidents, incidents, and near misses as well as selected exposure data such as hours and miles flown by air carriers. A detailed listing of data maintained by NASDAC is contained in Table 3-1 .

TABLE 3-1

DATA BASES AVAILABLE in NASDAC

Source	**Data Range**
National Transportation Safety Board Aviation Accident Database	1983 - Current

[6] A discussion of these and other techniques may be found in *Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment*, Society of Automotive Engineers Aerospace Recommended Practice (ARP) 4761, Warrendale PA, 1996 and in K. G. Vohra, “Statistical Methods of Risk Assessment for Energy Technology,” in *Low-Probability High-Consequence Risk Analysis: Issues, Methods, and Case Studies*, edited by Ray A. Waller and Vincent T. Colvello, Plenum Press, New York, 1984.

[7] For a discussion of such techniques see H. F. Martz and M. C. Bryson, “Predicting Low-Probability/High-Consequence Events,” in *Low-Probability High-Consequence Risk Analysis: Issues, Methods, and Case Studies*, edited by Ray A. Waller and Vincent T. Colvello, Plenum Press, New York, 1984.

NTSB Safety Recommendations/FAA Responses	1963 - Current
NAIMS -Pilot Deviations(PDS)	1987-Current
NAIMS-Operational Errors & Deviations (OEDS)	1985 - Current
NAIMS-Near Midair Collisions (NMACS)	1987 - Current
NAIMS-Vehicle/Pedestrian Deviations (VPDS)	1988 - Current
NAIMS - Runway Incursions (RI)	1988 - Current
FAA Accident/Incident System (AIDS)	1978 - Current
Service Difficulty Reporting System (SDRS)	1986 - Current
Aviation safety Reports	1988 - Current
Airclaims Database (AC)	1952 - Current
General Aviation activity (GA) Survey	1992 & 1993
NFDC - Landing Facilities (LF)/Airports (APT)	Current
NFDC - Air Route Traffic Control Center(ARTCC)	Current
NFDC - Radio Fix(FX)	Current
NFDC - Location Identifier	Current
NFDC - Navigational aids(NA)	Current
Aircraft Registry(AR)	Current
Aviation System Indicators(SI)	1983 - Current
Aircraft Operations Data - tower counts	1987 - Current
BTS - Form 41 Activity (T1) for large carriers	1974 -Current
BTS - Form 41 Activity (T2) by carrier/aircraft. type	1968 - Current
BTS - Form 41 Activity(T3) by carrier/airport	1990 - Current
BTS Bulletin Board System (Form 41 financial data)	1992 - Current
BTS - Form 41, 298-C, etc.	Current
FAA Aviation Safety Analysis Systems(ASAS)	Current
FAA Flight Standards Info. systems (FSIS)	Current
Aviation Data CD-ROM(Pilots, Aircraft, Owners, Mechanics, Medical Examiners, Airports, SDRS, Air taxis, Schools)	Current
ATP Navigator(Airworthiness Directives, Associated Service Information, Type Certificates, Supplemental Type Certificates, Advisory Circulars, Federal aviation Regulations, and Orders)	Current
Aviation Publications (FARS, AIM, Advisory Circulars, and Airworthiness Directives)	Current
Jane’s	Current

Selected NASDAC databases and exposure data--including the National Transportation Safety Board Aviation Accident Database, Near Midair Collisions, FAA Accident/Incident System, and selected Bureau of Transportation Statistics Form-41 data--are also available on the internet at http://nasdac.faa.gov/internet.

B. Capacity Increases which Reduce Congestion Related Delay[8]

The major reason for operating the air traffic control system is to allow many aircraft to use the same airspace simultaneously without colliding with one another. The capacity of the ATC system to handle aircraft safely is a given for any particular weather situation. As this level is approached, some aircraft must wait to use the system or various parts of it until they can be accommodated. This waiting imposes costs both in terms of aircraft operating expenses and the value of wasted passengers' time. Estimation of the delay benefits of a new project or regulation requires measurement of the aggregate annual aircraft operating time and passenger time which the new proposal will save. This saving is the difference between the delays currently experienced and those which would be experienced with the proposed new project or regulation. Once determined, the value of this saved time can be valued in dollars using standardized values.[9]

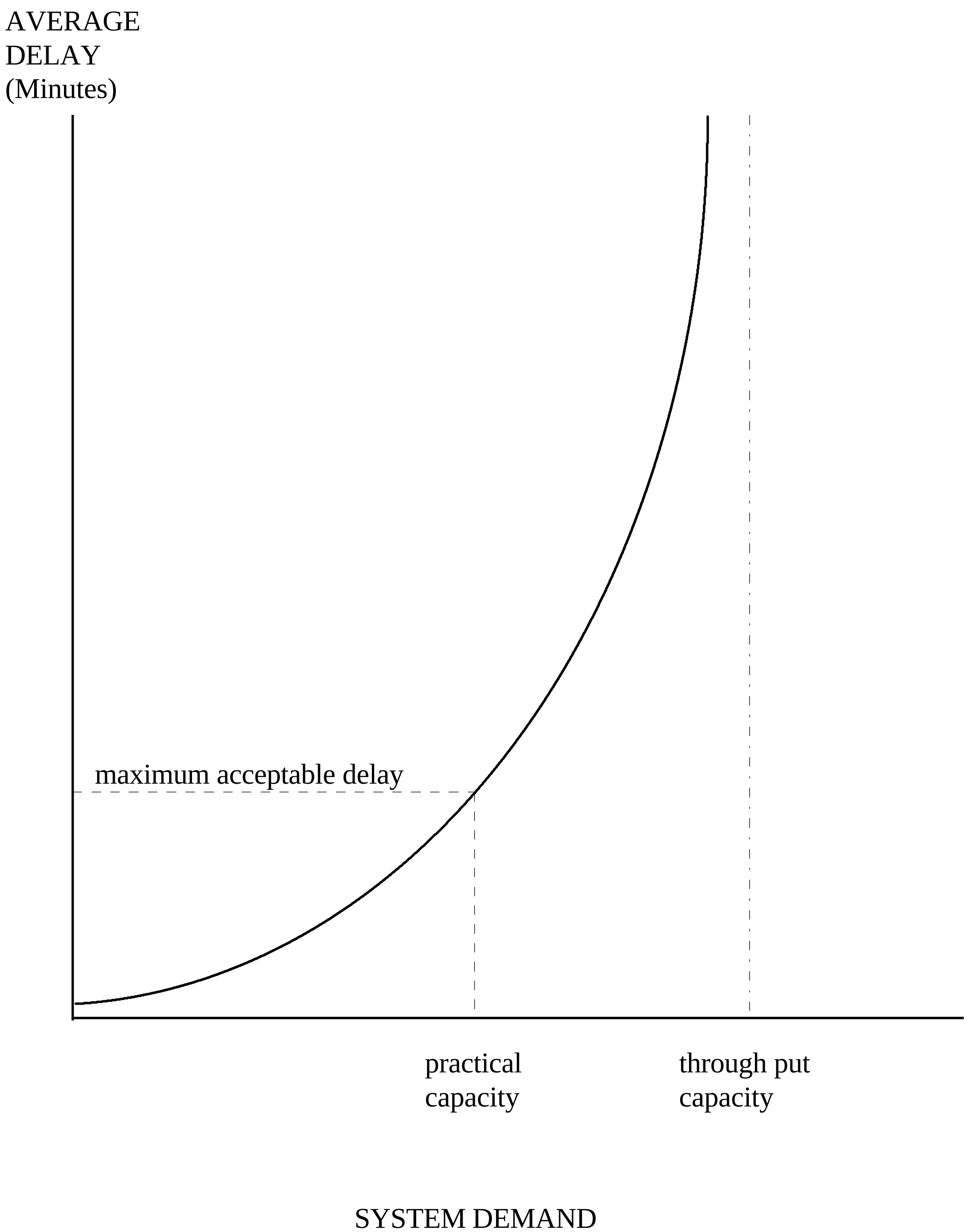
The estimation of delay reductions that a particular proposed project or regulation can be expected to produce requires that the relationship between average delay, capacity, and system demand for the segment of the ATC system of interest be determined for both the existing system and the proposed new one. Although such relationships will differ from situation to situation, their general form is depicted in Figure 3-2. As indicated, two definitions of capacity are relevant in defining this relationship. One is the "through put" measure. It defines the absolute number of system users that can be served in a given period of time, provided that a user is always present waiting to use the system. The second measure is that of "practical" capacity. It provides a measure of the ability of a given system to accommodate users subject to some maximum acceptable level of delay. As shown, average delay is low at low levels of demand and increases as demand approaches capacity, as defined under either definition. As demand exceeds "practical"

[8] Another type of capacity increase is the provision of facilities where none now exist. See section III.E.5 of this chapter for a discussion of the benefits associated with the construction of a new airport where there currently is none.

[9] Values for passenger time are provided in “The Value of Saving Travel Time: Departmental Guidance for Conducting Economic Evaluations,” Office of the Secretary of Transportation, April 9, 1997. Values for aircraft operating cost are provided in *Economic Values for Evaluation of Federal Aviation Administrative Investment and Regulatory Programs*, FAA Report FAA-APO-89-10, October 1989.

FIGURE 3-2

RELATIONSHIP BETWEEN CAPACITY
AND AVERAGE DELAY



capacity, delay exceeds the acceptable level. And as demand pushes up against "through put" capacity, delays begin to become infinite. This occurs because the number of users demanding service, per time period, begins to become greater than the ability of the system to serve them, resulting in an ever growing line of users waiting for service.

It is important to note that delays began to occur before capacity, under either definition, is reached. This happens because of the random nature in which system users demand services. If all users of a system consistently arrived at evenly spaced intervals, the system could provide service hourly to a number of users equal to the "through put" capacity rate. No delay would occur until "through put" capacity was actually exceeded. In actuality, system users do not arrive consistently at evenly spaced intervals. Sometimes several users arrive at one time and sometimes no one arrives. As a consequence, some of those who arrive at the same time as do others must be delayed.

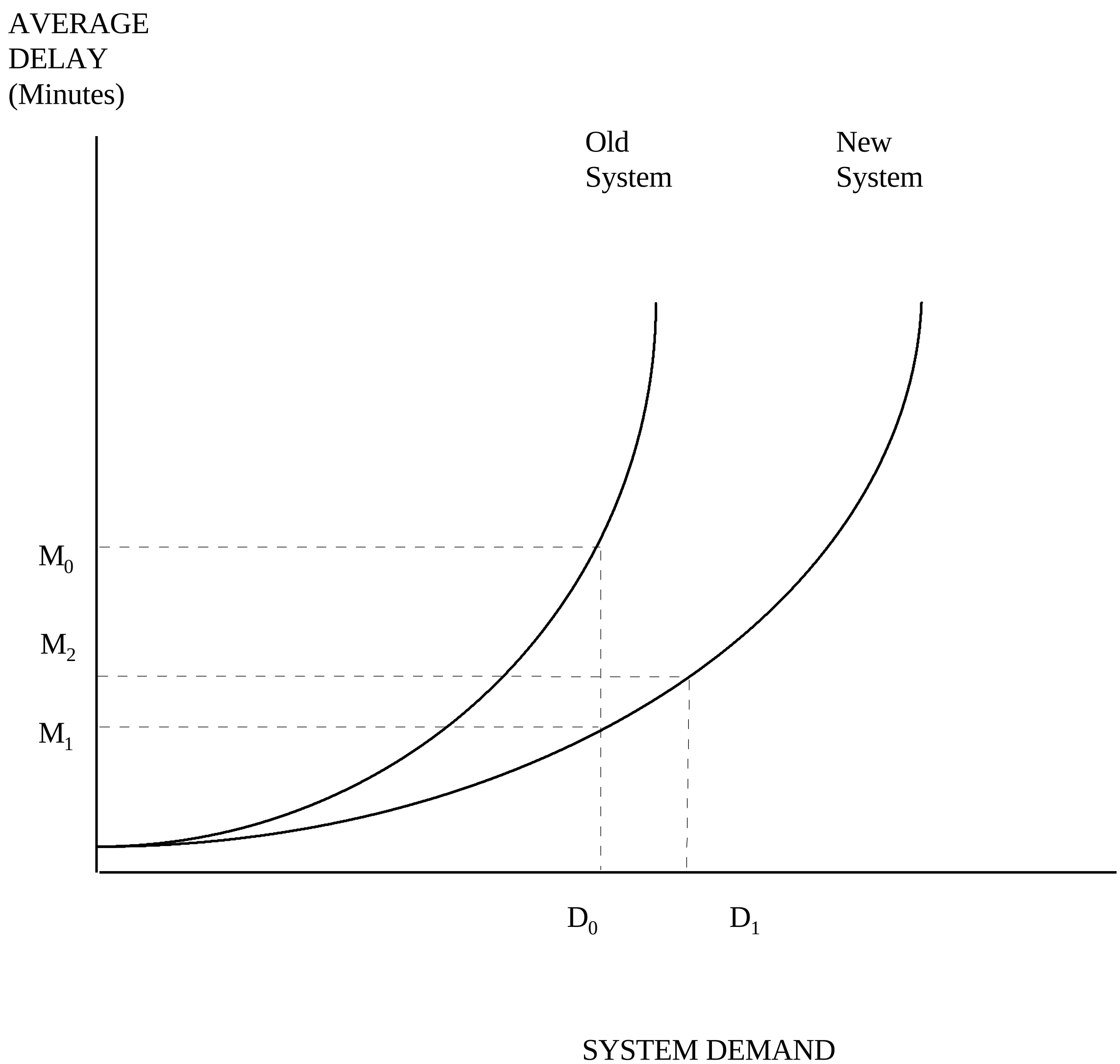
Measurement of capacity and delay benefits requires that the relationship depicted in Figure 3-2 be determined for both the existing system and the proposed new one. The general form of such relationships is shown in Figure 3-3. Each has the same general form as that of Figure 3-2, but with the proposed new system having greater capacity and lower average delays than the old one at each level of demand.

The average delay reduction per system user at the current level of demand, D_0, is M_0 - M_1 minutes. This is not the delay reduction that will occur if the indicated capacity increase is provided at demand level D_1 after system users have adjusted to the increase, however. Capacity improvements will reduce the costs of using the system both in terms of passenger time and aircraft operating expense. As indicated in Figure 3-1, cost reductions will generally lead to an increase in the quantity of any good or service demanded. In this case, assume system demand increases from D_0 to D_1 resulting in delay of M_2 per user. This level of delay is above M_1 and represents that level which will result from the indicated increase in capacity once demand has adjusted to the lower costs brought about by the capacity increase.

Having determined the average delay per system user after demand adjustments, it is now necessary to value these delay reductions. For users of the system before the capacity improvement, valuation is given by total cost savings per user. Because most delay reduction activities are air terminal area related, it is convenient to define user as an operation for the remainder of this discussion. The value of delay reduction for that level of operations that was occurring before the capacity improvement is equal to M_0 - M_2 minutes multiplied by the operating cost of the aircraft plus M_0 - M_2 minutes multiplied by the average number of passengers per aircraft and the value of passenger time. The average number of passengers per aircraft must be determined by the analyst in each specific case.

FIGURE 3-3

DELAY REDUCTION MEASUREMENT



For operations induced by the lower costs per user brought about by the capacity increase, value will be less because each additional unit of a commodity is valued less by consumers, as explained in Section II of this chapter. Value is given by the change in benefits accruing to passengers and air transportation service providers less the additional costs required to produce these benefits. Under conditions of competition in the air transportation industry, it can be shown that these net benefits can be approximated by one half of the number of additional operations, D_1 - D_0 in Figure 3-3, multiplied by M_0 - M_2 minutes multiplied by the operating cost of the aircraft plus one half of the number of operations, D_1 - D_0, multiplied by M_0 - M_2 minutes multiplied by the average number of passengers per aircraft multiplied by the value of passenger time.[10] Total delay benefits are equal to this amount plus the benefits for those operations already being conducted before the capacity increase. Finally, it should be noted that this procedure must be applied to each time period over the life of the capacity improvement. This requires that values for system demand be estimated for each year assuming both that the capacity improvement is and is not put in place.

The actual estimation of delay reduction usually requires the use of a model, although simpler analyses may be based on published relationships derived from models and/or empirical observation.[11] A host of different such models exist. Depending on the particular situation and proposed project or regulation, the analyst must choose (or develop) an appropriate model. Important factors in selecting a suitable model are the segment of the National Airspace System (NAS) which is to be analyzed and the level of detail required. A recent survey of available models classifies them by NAS segment of coverage and level of detail.[12] Segment of coverage differs across models, which may be

[10] The procedure is an approximation for several reasons. First, it assumes, correctly or not, that demand curves can be represented as straight lines over the relevant range of interest. Second, it assumes that all passengers can be represented by a single "representative passenger." Finally, implicit in the procedure is the assumption that passengers of various types at various airports increase their system usage in response to a reduction in delay by the same proportion. A detailed discussion of the limitations of this procedure, as well as attempts to improve upon it are contained in Robert A. Rogers, John L. Moore, and Vincent J. Drago, *Impacts of UG3RD Implementation on Runway System Delay and Passenger Capacity*, Final Technical Report, Department of Transportation, March 31, 1976.

[11] A number of relevant capacity, delay, and airport design relationships suitable for simpler analyses that must be completed quickly may be found in *Airport Capacity and Delay*, FAA Advisory Circular 150/5060-5, September 9, 1983, Change 2 to *Airport Capacity and Delay*, December 1, 1995, and *Airport Design*, FAA Advisory Circular 150/5300-13, September 29, 1989.

[12] A.R. Odoni *et al*, *Existing and Required Modeling Capabilities for Evaluating ATM Systems and Concepts*, International Center for Air Transportation, Massachusetts Institute of Technology, March 1997, Chapter 2. This report may be downloaded from http://web.mit.edu/aeroastro/www/labs/AATT/aatt.html

divided into enroute airspace models and terminal areas models. Terminal area models may be further sub-divided into terminal airspace, runway and final approach, and apron and taxi way models.

High detail models typically recognize specific aircraft on an individual basis and simulate their movement through a segment of the NAS. Their use is highly resource intensive--often requiring several months or more of effort. They are frequently employed in pre-design engineering studies and for benefit-cost analyses of large, high cost projects and regulations with substantial impact. Intermediate detail models are detailed macro models of one or more parts of the NAS. Although they lack the aircraft specific detail of the high detail models, they can be resource intensive and are suitable only for major benefit-cost analyses. Finally, there are the low detail models. These are relatively easy to utilize and are suitable for most policy and benefit-cost analyses where the objective is to quickly obtain appropriate answers and assess the relative performance of a wide range of alternatives. Some available models are summarized in Table 3-2.

TABLE 3-2

SELECTED CAPACITY and DELAY MODELS

Model	Developer (Availability)	Coverage	Level of Detail
FAA Airfield and Capacity Model	FAA/Mitre (CAASD) (NTIS: AD-A104 154/0)	Runway and Final Approach	Low
DELAYS	MIT (MIT Operations Research Center)	Runway and Final Approach	Low
NASPAC	FAA/Mitre (ASD-130)	Runway and Final Approach Terminal Area Airspace Enroute Airspace	Intermediate
SIMMOD	FAA (ASD-400)	Aprons and Taxiways Runway and Final Approach Terminal Area Airspace Enroute Airspace	High
ADSIM	FAA (Technical Center) (NTIS: PB84-171560, PB84-171552)	Aprons and Taxiways Runway and Final Approach Terminal Area Airspace	High
RDSIM	FAA (Same as ADSIM)	Runway and Final Approach	High
The Airport Machine	Airport Simulation International Inc.	Aprons and Taxiways Runway and Final Approach	High

C. Avoided Flight Disruptions

One particular class of FAA investments--establishment of non-precision or precision instrument approaches--gives rise to particular type of benefit know as an avoided flight disruption. Instrument approaches have the characteristic of allowing operators to land aircraft in weather conditions under which they could not land without establishment of the approach. Because such approaches permit landings at weather minimums below what would be possible without the approach, they permit flights to land that would otherwise be disrupted. (Flight disruptions are a form of delay, albeit one that is not caused by congestion.)

Weather caused flight disruptions impose economic penalties on both aircraft operators and users. When the weather is below landing minimums at the destination airport, the operator can take one of four actions:

1. fly to the intended airport and hold until the weather improves.
2. fly to the intended airport and divert to another airport if the weather does not improve.
3. on a multi-leg flight, operate the flight and overfly the below minimums airport.
4. cancel the flight.

Estimation of the benefit of avoiding a flight disruption requires that the relative occurrence of each of these four possible outcomes be determined. It is also necessary to estimate the costs associated with each of these possible outcomes. This is done by constructing a scenario of events associated with each and then measuring costs, including aircraft operating cost, passenger time lost, passenger handling cost, and aircraft repositioning cost, for each scenario. The relative occurrence of each outcome is then used as a weight to calculate the average cost of a flight disruption.

The final step in estimating the benefits of an investment in an instrument approach is to determine the number of such disruptions that can be avoided if the approach is established. This can be done by estimating from weather data the percent of the time that the weather at the airport will be below the minimum existing before the approach is established and above the minimum that will be achievable after the approach is established. This percentage is then used together with a measure of annual operations at the airport to determine the number of landings that will be possible with the establishment of the approach that would not be possible without it. Multiplying these landings which are no longer disrupted by the cost of a flight disruption yields the annual benefit of establishing the approach.[13]

D. Cost Savings

Investment and regulatory decisions may result in cost savings to both the private sector, the FAA, and other governmental agencies. These savings may come in the form of direct cost savings where actual dollar outlays are reduced, or they may be reflected in efficiency gains. In the second case, output levels achievable with existing resources go up, but actual costs remain constant. Given enough time, it is usually possible to shift such resources from one use to another if it is not desired to increase output by the full amount made possible by the increased efficiency.

Examples of direct cost savings are investments and/or regulations which reduce utility costs or fuel consumption. Included would be investments in more efficient heating and cooling equipment, aircraft engines, and solid state electronics. Also under this category would be regulations or procedures to minimize aircraft fuel consumption such as direct routings and free flight. Direct cost savings of an investment or regulation should be measured as the actual value of the savings expected to occur.

An example of efficiency gains is agency investments to increase employee productivity. Included would be the continued automation of the air traffic control system which has relieved controllers of many record keeping functions and the near universal acquisition and continuous upgrading of personal computers and applications software for most FAA employees. In the case of ATC automation, additional productivity has been reflected in greater output. For personal computers, it has been possible to shift employee resources away from document and graphics preparation to other tasks. These gains should be measured by the value of the additional benefits which the more productive workers can now provide. For ATC automation this would be the value of the additional output. For personal computers, it would be the value of the other tasks which employees may now perform in the time saved by the use of the computers.

E. Other

The above categories constitute most of the benefits that can typically be expected to flow from FAA investment and regulatory activities. Any analysis, of course, should include all

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[13] A detailed algorithm for estimating the benefits of avoided flight disruptions for various user classes operating to and from hub and non-hub airports has been developed by the Office of Aviation Policy and Plans. It is published in *Establishment Criteria for Loran-C Approach Procedures*, FAA Report FAA-APO-90-5, June 1990, Appendix A.

known benefits whether or not they can be classified in the major categories. The following presents selected examples of other such benefits that have been identified in previous studies.

1. Noise Reduction

The provision of air transportation services generates noise which imposes costs or dis-benefits on those who are subjected to this noise. Government investments which promote aviation may have the accompanying effect of increasing aircraft noise. Other Governmental activities have been undertaken to reduce aircraft-generated noise. The benefits of noise mitigation activities are the reductions in noise-produced costs which these activities achieve. These noise related costs and benefits should be addressed in economic analyses of activities which result in increases or decreases in aircraft noise.

Although it is possible to establish a conceptual framework which correctly measures the social cost of aircraft noise, deriving empirical estimates for such a framework is a difficult undertaking requiring numerous assumptions and estimation compromises.[14] As a consequence, benefits of noise abatement undertakings (or costs associated with increased noise levels accompanying a project) are most frequently developed in terms of physical units such as area, area size in square miles, number of dwelling units, or number of persons removed from (or added to) areas experiencing specified levels of noise.[15]

The first step to measure these physical units is to identify the area around an airport which is impacted by noise. This area, designated as the noise footprint, may be mapped by use of a model. The FAA Integrated Noise Model (INM) is one such model which is widely used by the aviation community for mapping and evaluating aircraft noise impacts in the vicinity of airports.[16] This model is typically used in the U.S. for FAR Part 150 noise compatibility planning and FAA Order 1050 environmental assessments and environmental impact statements. It permits the noise of different aircraft types on

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[14] For a discussion of such issues, see E. J. Mishan, *Cost-Benefit Analysis*, Geroge Allen and Unwin, London, 1982, pp. 346-362, and D.W. Pearce and A. Markandya, *Environmental Policy Benefits: Monetary Valuation*, OECD 1989.

[15] This approach is illustrated by two recent studies. *A Study of the High Density Rule,* DOT Report to Congress, May 1995, evaluated a possible regulation revision, one result of which would have been a change in noise impacts. *Final Report of the Economic Analysis Subgroup*, ICAO Committee on Aviation and Environmental Protection, Bonn, June 1995, analyzed alternative environmental policies and their expected outcomes.

[16] *FAA Integrated Noise Model(INM) Version 5.1 User's Guide*, FAA-AEE-96-02, December 1996.

specified flight paths to be measured by one of several common noise measures. It is thus possible to measure the noise which currently exists and that which will exist after a change in aircraft type mix, flight path, number of operations, or other variables.[17]

The measures of noise provided by the model deal with two characteristics of noise: single event noise intensity and the cumulative number of occurrences of the noise events. Single event noise intensity measures are useful for such purposes as measuring the noise generated by a particular engine or in determining the amount soundproofing required to achieve desired indoor noise levels. The general annoyance associated with noise is usually best assessed by a cumulative measure. One such measure is the Day-Night Average Sound Level (DNL). Scaled in decibels, it represents the cumulative impact of aircraft noise over a 24-hour period in which aircraft operations during the nighttime (between 10 p.m. and 7 a.m.) are assessed a 10 dB penalty to account for the increased annoyance in the community.

FAA has also developed a simpler noise model--the Area Equivalent Method (AEM). It is a screening tool that provides an estimate of the size of the land mass enclosed within a level of noise, not a noise footprint, as produced by a given set of aircraft operations. The AEM produces contour areas (in square miles) for the DNL 65dB noise level and any other whole DNL value between 45 and 90dB. The AEM assists users in determining whether a change in aircraft mix or number of operations warrants additional analysis using the INM.[18] Once the noise footprint is determined, the physical impacts of the increase or decrease in noise may be determined by tabulating the change in dewelling units and population subject to each level of noise intensity.

2. Missed Approach Benefit

In making an instrument or visual approach to a landing, the pilot almost always has the option of aborting the approach if it is judged to be unsatisfactory by executing what is known as a missed approach. This requires the pilot to fly around and try again. This maneuver, called a go-around, results in both aircraft operating expenses and wasted time. The missed approach benefit arises when certain approach aids which help reduce missed approaches and avoid go-around costs are installed. It may be estimated for a single approach by calculating the probability of a missed approach being averted by a landing aid and multiplying this probability by the cost of a go around. Summing this per

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[17] FAA has also developed a model for evaluating noise at Heliports. See *HNM-Heliport Noise Model Version 2.2 User's Guide,* DOT/FAA/EE/94-01, February 1994.

[18] *Area Equivalent Method Version 3 Users Guide*, DOT/FAA/EE-96-04, September 1996.

approach benefit across all approaches occurring in a particular year will yield the total annual benefit in that year.[19]

3. Avoided Accident Investigation Costs

Another cost of aviation accidents, in addition to fatalities, injuries, and property damage, is the cost of investigating them. The National Transportation Safety Board (NTSB) is responsible for the investigation of all aircraft accidents. NTSB is typically assisted by others in its investigations. NTSB conducts two types of investigations: major investigations which are directed by NTSB headquarters in Washington and field office investigations which are conducted by NTSB field offices. Major investigations are conducted primarily for major air carrier disasters involving numerous fatalities and substantial property damage. They are characterized by the dispatch of an investigative party--go team--to the accident site and usually involve substantial support by the FAA and involved private parties such as the airline, airframe and engine manufacturers, avionics manufactures, component and sub-component suppliers, etc.

Field investigations may be further divided into regular investigations and limited investigations. Field office regular investigations are much smaller in scope than major investigations. They are conducted for air carrier accidents involving limited loss of human life and for most fatal general aviation accidents. Limited field office investigations are conducted for most other accidents. FAA provides significant support to NTSB in the conduct of field office investigations.

Costs for each type of investigation and average investigation costs for air carrier and general aviation accidents may be obtained from the Office of Aviation Policy and Plans.

4. Regulatory Changes in Capacity at Access Capped Airports

In order to avoid excessive congestion at several of the nation's airports, access is capped through regulations which establish a fixed number of landing and takeoff rights ("slots"). Any change to the number of such slots can be expected to generate both benefits and costs for airport users. The primary benefit resulting from an increase in slots is the value to consumers of the additional trips made possible by the increase. Referring to Figure 3-1, and assuming that the number of slots is increased from a current level of Q_1 to a new level of Q_3, the value or benefit of Q_3-Q_1 slots is indicated by the area Q_1ABQ_3. This represents the maximum amount that consumers would be willing to pay for the trips

[19] Specific methodology, which may be adapted to calculate such benefits is contained in "Missed Approach Probability Computations of the FAA/SCI (vt) Approach Aid Model," Interim Draft Report, Contract DOT-FA78WA-4173, October 1980.

that these slots could support. To determine if a proposed increase in slots would yield a *net* benefit, it is necessary to offset the costs generated by the additional slots against the their value. Such costs include the costs to operate the additional flights which would use the additional slots, the additional aircraft operating cost to current airport users associated with increased delays that might arise because of the increase in slots, the value of passenger time associated with the delay experienced by the passengers flying in the new slots, and the value of passenger time to current passengers associated with increased delays that might arise because of the increase in slots.[20]

5. Construction of New Airport where None Currently Exists

From time to time it is necessary to evaluate the construction of a new airport where one does not currently exist. Several benefits including those identified here are associated with such a project.

First, is the reduction of transportation costs currently incurred by travelers and shippers to and from the region to be served by the new airport. Current land and/or water transportation systems into and out of the region have both dollar and time costs associated with them. An airport will support air transportation into the region. This substitute to existing modes of transport will reduce time costs of traveling to the region and may either reduce or increase the dollar cost of such transportation. The net reduction in time and dollar costs to existing travelers or shippers constitutes a benefit. Second, to the extent that costs of transportation are reduced, additional transportation will be induced. The maximum amount that travelers and shippers are willing to pay for this induced transportation will be another benefit.

These two benefits may be illustrated graphically by reference to Figure 3-1. For purposes of this illustration, quantity refers to the volume of trips by all modes into and out of the region. Price represents the "full price of travel" which is defined as the dollar cost of a trip plus the time cost where time cost is the amount of time consumed by a trip multiplied by the dollar value of time. Prior to the introduction of air transportation, the cost of a trip is equal to P_1 and Q_1 trips are consumed. Introduction of air transportation has the effect of reducing the full price of travel from P_1 to P_3. The benefit to all current travelers is indicated by P_1ACP_3, that is the travel cost savings per trip times the number of trips. The value of the induced demand for additional trips is given by the triangle ABC which is equal to half the decline in trip price, P_1-P_3, times the increase in trips, Q_3-Q_1.

[20] For an example of the estimation of the benefits and costs associated with a change in capacity controls at certain major airports, see "Appendix G to Technical Supplement No. 3--Analytical Concepts and Methods, A Study of the High Density Rule," Report to Congress, Department of Transportation, May 1995.

Additional benefits associated with economic development may also occur depending on the particular situation. If the region is particularly suited to producing--can produce at lower cost than others can--a particular good or service which must be shipped quickly to a distant market, building of an airport may allow the regional economy to produce and export this good more cheaply than it can be produced elsewhere thus improving the welfare of those who consume it. The reduction in the delivered cost of this good or service together with the value of additional consumption of it because of its now lower cost are benefits of constructing the new airport. An example would be fresh flowers that can be more cheaply grown on a distant tropical island than closer to their consumers in a greenhouse. Construction of an airport on the island makes possible the cheaper production of the flowers. Another example would be where the central location of the new airport would make it a low cost location to warehouse inventory intended to be shipped on a just-in-time basis. Distribution cost saving associated with the particular regional location would be a benefit of the new airport.

Depending on the particular case, additional economic development benefits may be present. Such benefits will posses the common characteristic that they arise because the new airport lowers transportation costs and thus facilitates the development of a new industry or the expansion of an existing one. It should be noted that job creation from airport construction is not a benefit. While jobs are created at the site of the construction, absent significant unemployment the workers who fill them must be hired away from other jobs where they would have contributed to the economy. Also, industry attracted from another location should not be considered a benefit of the new airport. Although this site may gain from the migrated industry, another location loses. Any reduction in production cost resulting from the industry relocating, however, should be captured as a benefit of the new airport.